2002

Effect of Diet Complexity and the Additive Effect of Pharmacological Levels of ZnO and Carbadox on the Performance of Weaned Pigs

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SWINE 2001 - 7

The scientific literature documents the efficacy of antibacterial feed additives for weaned pigs. More recently, feeding therapeutic levels of supplemental zinc (Zn) from zinc oxide (ZnO) stimulated voluntary feed intake and weight gain of young pigs. Over the last decade, research demonstrated that swine diets containing sub-therapeutic levels of various antibiotics combined with pharmacological levels of copper (Cu) resulted in better performance than when either ingredient was provided individually. In 1982, an additive improvement in performance was found when a sub-therapeutic level (55 mg/kg) of carbodox (CARB) and high level of Cu (125 mg/kg) were provided in combination in a corn-soybean meal diet.

The interactive effects of Cu from copper sulfate ($CuSO_4$) and Zn from ZnO in diets for weanling pigs on performance have been evaluated, and the use of 3000 mg/kg Zn alone provided greater performance than the use of both Cu and Zn. Because Cu and Zn have independent biological growth promoting properties, it is necessary to determine if swine diets containing an antimicrobial agent in combination with 3000 mg/kg Zn as ZnO may result in better performance than when either is provided individually.

The objectives of this study were (1) to determine the additive effects of 3000 mg/kg Zn as ZnO and CARB on weaned pig performance and (2) to evaluate whether simple nursery diets containing Zn as ZnO support performance that is similar to complex (phase I and phase II) nursery diets.

(Key Words: Weaned pigs, Diet complexity, Zinc oxide, carbadox.)

Experimental Procedure

One hundred twenty crossbred pigs averaging 7.90 kg were weaned between 21 and 28 days of age and allotted on the basis of weight, sex, and ancestry to dietary treatments in a randomized complete block design. There were six dietary treatments replicated in four weight blocks with five pigs per pen. Four of the six dietary treatments were simple diets (Table 1) containing corn, soybean meal, 1% soybean oil, and 20% dried edible whey with 0 or 3000 mg/kg Zn as ZnO and 0 or 55 mg/kg CARB arranged in a 2 x 2 factorial. These diets were fed for the entire 28 day period. The two additional treatments were complex diets (Table 2) fed in a phase I-phase II sequence as reference diets in making comparisons with simple diets. These two diets included 0 or 55 mg/kg CARB. The complex diet fed during phase I (first 14 days) contained corn, soybean meal, 1% soybean oil, 20% dried edible whey, 10% lactose, and 6% spray-dried porcine plasma. The complex diet fed during phase II (last 14 days) contained corn, soybean meal, 1% soybean oil, 20% dried edible whey, and 2% blood meal.

Dietary treatments were:

- Simple diet
- Simple diet with 3000 mg/kg added Zn from ZnO
- Simple diet with 55 mg/kg CARB
- Simple diet with 3000 mg/kg added Zn from ZnO and with 55 mg/kg CARB
- Complex diets
- Complex diets with 55 mg/kg CARB.

Simple and phase I diets were formulated to provide 1.40% lysine. Phase II diets were formulated to provide 1.20% lysine. All diets contained at least 100 mg/kg added Zn. Levels of all essential dietary nutrients in the experimental diets were at or greater than NRC (1988) nutrient requirements. Calculated and chemically determined nutrient content of experimental diets is shown in Table 3.

Pigs were weaned in two groups each providing 60 pigs, which were placed in two

TABLE 1.. COMPOSITION OF SIMPLE DIETS WITH AND WITHOUT ZINC OXIDE AND/OR CARBADOX, %

Added Zn, mg/kg	0	3000	0	3000
Added CARB, mg/kg	0	0	55	55
Ingredients/Treatments	1	2	3	4
Ground corn	43.05	42.63	42.57	42.15
Soybean meal, 44%	33.34	33.34	33.58	33.58
Edible dried whey	20.00	20.00	20.00	20.00
Soybean oil	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.14	1.14	1.15	1.15
Limestone	.70	.70	.69	.69
Salt	.25	.25	.25	.25
Carbadox[ab]	0	0	.25	.25
L-lysine HCl[b]	.18	.18	.17	.17
DL-methionine[b]	.20	.20	.20	.20
Premix[bc]	.14	.14	.14	.14
Zinc oxide[bd]	0	.42	0	.42
Total	100.0	100.0	100.0	100.0

[a]2.2% carbadox (Mecadox® premix-10) produced by Pfizer, New York, NY 10017.
[b]Premixed with ground corn before adding with macro ingredients. Ground corn added to give a total inclusion rate of 1%.
[c]Premix provided the following per kg of diet: 100 mg Zn, 75 mg Fe, 25 mg Mn, 7.5 mg Cu, 175 :g I, 300 :g Se, 16.5 IU vitamin E, 3.3 mg riboflavin, 17.6 mg niacin, 13.2 :g vitamin B_{12}, 2.2 mg vitamin K_3, 13.2 mg pantothenic acid, 3960 IU vitamin A, and 396 IU vitamin D_3.
[d]Zinc oxide (72% Zn) manufactured by Zinc National, S.A.

nursery rooms at the South Dakota State University Swine Research Center. Pigs were housed in 1.2 m x 1.2 m raised pens equipped with either Tri-bar metal or vinyl floors and provided with one stainless steel self-feeder and one stainless steel nipple waterer. Nursery temperatures were maintained within the range of thermoneutrality in the mechanically ventilated nursery rooms starting at 30°C and decreased 2°C each week. A 24-hour constant light schedule was maintained.

Pig weight, feed consumption, and feed wastage were measured weekly. Feed samples collected during the experimental period were pooled by diet and analyzed for crude protein, Ca, P, Zn, and lysine.

Data were analyzed as a randomized complete block design. The statistical models included the effects of block, Zn, CARB, and Zn x CARB interaction for the 2 x 2 factorial and the effects of room, replication, treatment, room x treatment interaction, and replication x treatment interaction for the analysis of the six treatments. Pen was the experimental unit. Orthogonal contrasts were created to compare means for simple diets and complex diets and feed additives.

Results

Main effect means for gain, feed intake and wastage, and gain/feed are shown in Table 4. There was no Zn by CARB interaction (P>.10) for any period studied.

For the initial 7-day (P<.05), 14-day (P<.01), and overall 28-day (P<.01) periods, pigs fed simple diets with 3000 mg/kg added Zn as ZnO had greater gains than those fed the simple diets without added Zn. There was no response to added Zn from day 15 to 28 (P>.10). Carbadox improved ADG from day 15 to 28 (P<.10) and overall (P<.05), but did not affect ADG for other periods (P>.10). Feed intake was unaffected (P>.10) by added Zn or CARB during the initial 7 days. Pigs fed simple diets with 3000 mg/kg added Zn had greater (P<.05) ADFI than those fed simple diets without added Zn for the first 14-day, last 14-day, and the overall 28-day periods. Adding CARB to the simple diet had no effect (P>.10) on ADFI from day 0 to 7 and day 0 to 14 but increased (P<.05) ADFI from day 15 to 28 and overall. Feed wastage was

TABLE 2. COMPOSITION OF COMPLEX DIETS WITH OR WITHOUT CARBADOX, %

	Phase I diets		Phase II diets	
Added Zn, mg/kg	0	0	0	0
Added CARB, mg/kg	0	55	0	55
Ingredients/Treatments	5	6	5	6
Ground corn	39.12	38.64	53.16	52.68
Soybean meal, 44%	21.19	21.43	21.19	21.42
Edible dried whey	20.00	20.00	20.00	20.00
Plasma, spray-dried[a]	6.00	6.00	0	0
Blood meal, spray-dried[b]	0	0	2.00	2.00
Lactose[c]	10.00	10.00	0	0
Soybean oil	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.25	1.26	1.45	1.45
Limestone	.71	.70	.60	.60
Salt	.25	.25	.25	.25
Carbadox[de]	0	.25	0	.25
L-lysine HCl[e]	.17	.16	.15	.15
DL-methionine[e]	.17	.17	.06	.06
Premix[cf]	.14	.14	.14	.14
Total	100.0	100.0	100.0	100.0

[a]Porcine plasma 780 produced by NutriBasics.
[b]Spray-dried blood meal produced by NutriBasics.
[c]Lactose manufactured by Davisco International, Inc.
[d]2.2% carbadox (Mecadox® premix-10) produced by Pfizer, New York, NY, 10017.
[e]Premixed with ground corn before adding with macro ingredients to inclusion rate of 1%.
[f]Premix provided the following per kg of diet: 100 mg Zn, 75 mg Fe, 25 mg Mn, 7.5 mg Cu, 175 :g I, 300 :g Se, 16.5 IU vitamin E, 3.3 mg riboflavin, 17.6 mg niacin, 13.2:g vitamin B_{12}, 2.2 mg vitamin K_3, 13.2 mg pantothenic acid, 3960 IU vitamin A, and 396 IU vitamin D_3.

TABLE 3. NUTRIENT CONTENT OF EXPERIMENTAL DIETS (AS FED)

	Simple diets				Phase I diets		Phase II diets	
Added Zn, mg/kg	0	3000	0	3000	0	0	0	0
Added CARB, mg/kg	0	0	55	55	0	55	0	55
Nutrient/Treatment	1	2	3	4	5	6	5	6
Calculated								
Crude protein, %	21.00	20.96	21.00	20.96	19.96	20.00	18.20	18.20
Calcium, %	.80	.80	.80	.80	.80	.80	.80	.80
Phosphorus, %	.70	.70	.70	.70	.70	.70	.71	.71
Lysine, %	1.40	1.40	1.40	1.40	1.40	1.40	1.20	1.20
Zinc, mg/kg	125	3125	125	3125	125	125	125	125
Chemically determined								
Crude protein, %	20.72	20.37	21.01	19.72	19.85	19.74	17.12	17.43
Calcium, %	.66	.72	.71	.63	.71	.73	.70	.73
Phosphorus, %	.68	.69	.68	.65	.67	.72	.65	.69
Lysine, %	1.26	1.38	1.41	1.40	1.39	1.36	1.03	1.03

unaffected (P>.10) by added ZnO or CARB during any period. For the initial 7-day (P<.05) and 14-day (P.10) periods, adding Zn to simple diets improved feed efficiency over simple diets without added Zn but decreased (P<.05) feed efficiency from day 15 to 28. Added Zn had no effect (P>.10) on gain/feed for the overall period. There was no CARB effect (P>.10) on feed efficiency.

Gain, feed intake and wastage, and gain/feed for the six treatments are shown in

TABLE 4. EFFECT OF Zn ADDED AS ZnO AND CARBADOX ADDITIONS TO SIMPLE DIETS ON WEANED PIG PERFORMANCE (MAIN EFFECT MEANS)[a]

Item	Zn, mg/kg		Carbadox, mg/kg		±SD[b]
	0	3000	0	55	
Avg daily gain, g/day					
Day 0 to 7[d]	44	93	57	80	42
Day 0 to 14[e]	153	276	194	234	57
Day 15 to 28[f]	530	563	524	569	48
Overall[eg]	341	419	359	402	33
Avg daily feed intake, g/day					
Day 0 to 7	107	127	112	121	25
Day 0 to 14[e]	203	319	243	278	47
Day 15 to 28[eh]	775	902	784	893	63
Overall[eh]	489	610	514	586	45
Avg daily feed wastage, g/day					
Day 0 to 7	7	11	10	9	5
Day 0 to 14	16	22	17	21	9
Day 15 to 28	42	41	34	49	17
Overall	29	31	26	35	11
Gain/feed					
Day 0 to 7[d]	.39	.72	.49	.62	.22
Day 0 to 14[c]	.75	.86	.77	.84	.11
Day 15 to 28[d]	.69	.63	.67	.64	.04
Overall	.70	.69	.70	.69	.03

[a]No added Zn x carbadox interaction (P>.10).
[b]Standard deviation: each diet was replicated in four pens of five pigs, one pen removed day 0 to 7.
[c]P< .10, [d]P<.05, [e]P<.01 ZnO effect.
[f]P< .10, [g]P<.05, [h]P<.10 carbadox effect.

Table 5. Pigs fed the simple diet with pharmacological Zn and the simple diet with pharmacological Zn and CARB had lower (P<.06) ADG than pigs fed phase I diets from day 0 to 7 and similar (P>.10) ADG to pigs fed phase I diets during the initial 14 days. Adding 3000 mg/kg Zn to the simple diet resulted in greater (P<.05) ADG than feeding the phase II diet during day 15 to 28. Over the entire 28-day period, pigs fed the simple diet with added Zn had ADG that was similar (P>.10) to pigs fed complex diets. Pigs fed the simple diet with pharmacological Zn or the simple diet with pharmacological Zn and CARB had ADFI that were similar (P>.10) to pigs fed the phase I diet from day 0 to 7 and day 0 to 14 and greater (P<.10) than those fed the phase II diet from day 15 to 28. Over the entire 28-day period, pigs fed the simple diet with added Zn or the simple diet with added Zn and added CARB had similar (P>.10) ADFI to those fed complex diets. Pigs fed the simple diet with pharmacological Zn or the simple diet with pharmacological Zn and CARB had feed wastage that was greater (P<.05) than those fed the phase I diet from day 0 to 14 but similar (P>.10) to pigs fed the complex diets from day 0 to 7, day 15 to 28, and overall. For each period, pigs fed the simple diets with added Zn and CARB had similar (P>.10) gain/feed ratios to pigs fed the complex diets.

No additive effects of CARB to diets with ZnO were observed. However, there were additive effects of ZnO to the diet that contained CARB for ADG for day 0 to 14 (P<.10) and for gain/feed for day 0 to 7 (P<.05). Zinc supplied at 3000 mg/kg as ZnO provided maximum performance. These results would appear to be different from the equal performance of pigs fed copper and CARB individually and the greater additive response observed when both were included.

Performance of pigs fed simple diets that included ZnO or ZnO and CARB was equal to performance of pigs fed complex diets for the 28-day trial. In this trial, simple diets including 3000 mg/kg Zn supplied as ZnO provided for feed intake and pig growth at the same level as complex diets containing more expensive feed ingredients.

TABLE 5. EFFECTS OF DIET TYPE AND ADDITIVES ON PIG PERFORMANCE

	Simple diets				Complex diets		
Added Zn, mg/kg	0	3000	0	3000	0	0	
Added CARB, mg/kg	0	0	55	55	0	55	
Item/Treatments	1	2	3	4	5	6	±SD[a]
Avg daily gain, g/day							
Day 0 to 7[b]	43	71	45	116	129	193	60
Day 0 to 14[df]	120	268	185	283	227	336	64
Day 15 to 28[cd]	495	552	564	574	444	539	37
Overall[e]	308	410	375	428	335	438	45
Avg daily feed intake, g/day							
Day 0 to 7	108	117	105	147	143	197	41
Day 0 to 14[dh]	180	306	225	332	281	364	54
Day 15 to 28[be]	695	873	856	931	727	874	89
Overall[e]	437	590	540	631	504	519	69
Avg daily feed wastage, g/day							
Day 0 to 7	8	11	6	12	5	8	5
Day 0 to 14[b]	16	19	16	25	9	14	8
Day 15 to 28	36	32	48	50	30	43	17
Overall	26	25	32	38	20	28	10
Gain/feed							
Day 0 to 7[eg]	.37	.60	.40	.70	.90	.98	.22
Day 0 to 14[e]	.66	.87	.83	.85	.80	.93	.07
Day 15 to 28[d]	.71	.64	.66	.62	.61	.62	.05
Overall	.70	.70	.70	.68	.67	.71	.02

[a]Standard deviation: each treatment was replicated in four pens of five pigs, one pen removed day 0 to 7.
Orthogonal contrasts:
[b]P<.10, [c]P<.01, treatments 2 and 4 vs treatments 5 and 6 (simple diets with ZnO vs complex diets).
[d]P<.05, [e]P<.01, treatment 1 vs treatments 2, 3, and 4 (within simple diets, no additive vs additive).
[f]P<.10, [g]P<.05, treatment 3 vs 4 (within simple diets, additive effect of ZnO to CARB).
[h]P<.10, treatment 2 vs 3 (within simple diets, ZnO vs CARB).
Treatment 2 vs 4 (within simple diets, additive effect of CARB to ZnO).

Summary

One hundred twenty crossbred pigs (7.90 kg) were weaned between 21 and 28 days of age and allotted to six dietary treatments (randomized complete block design) replicated in four weight blocks with five pigs per pen. Four of the six dietary treatments were simple diets containing corn, soybean meal, 1% soybean oil, and 20% dried edible whey with 0 or 3000 mg/kg Zn as ZnO and 0 or 55 mg/kg CARB arranged in a 2 x 2 factorial. The two additional treatments were complex diets with 0 or 55 mg/kg CARB fed in a phase I-phase II sequence as reference diets for making comparisons with simple diets for the 4-week trial. All diets contained at least 100 mg/kg added Zn.

There were no Zn by CARB interactions for any period studied. For the initial 7-day, 14-day, and overall 28-day periods, pigs fed simple diets with 3000 mg/kg added Zn as ZnO had greater ADFI and ADG than those fed simple diets without added Zn. For the initial 7-day and 14-day periods, adding Zn to simple diets resulted in greater feed efficiency than when simple diets without added Zn were provided but poorer feed efficiency from day 15 to 28. Carbadox improved ADG and increased ADFI from day 15 to 28 and overall.

Pigs fed the simple diet with pharmacological Zn and the simple diet with pharmacological Zn and CARB had lower ADG and similar ADFI from day 0 to 7 to pigs fed the complex diets. ADG and ADFI were similar during the initial 14 days and greater during day 15 to 28 for pigs fed the simple diets with added Zn. Feed wastage was greater for pigs fed simple diets than those fed the phase I diet from day 0 to 14 but similar to those fed the complex diets from day 0 to 7, day 15 to 28, and overall.

Pigs fed the simple diets with added Zn had similar gain/feed ratios to pigs fed the complex diets.

Overall, pigs fed the simple diet with added Zn had ADG, feed intake, and gain/feed that were similar to pigs fed complex diets.

Implications

Addition of CARB (55 mg/kg) or Zn (3000 mg/kg) supplied as ZnO increased gain and feed intake of weaned pigs fed simple diets consisting of corn, soybean meal, 1% soybean oil, and 20% dried edible whey. While the efficacy of each additive was demonstrated, no evidence for an additive effect of CARB over the response to ZnO was observed. Maximum performance was obtained when Zn was supplied with or without CARB.

Inclusion of 3000 mg/kg of Zn as ZnO to simple diets provided for feed intake, gain, and feed efficiency similar to that obtained with complex diets consisting of more expensive ingredients. This suggests that more economical diets might be fed during the early growth stages of weaned pigs as long as ZnO is included at pharmacological levels.